eRD6 Progress Report

Kondo Gnanvo

On Behalf of eRD6

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

July 13, 2017

The eRD6 Consortium: Tracking and PID detector R&D

- **Brookhaven National Laboratory (BNL)**
  People: E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody
  R&D: Mini-Drift detector; TPC/Cherenkov prototype (TPC-C); zigzag pad development.
- **Florida Institute Of Technology (FIT)**
  People: M. Bomberger, M. Hohlmann, F. Izquierdo
  R&D: Large & low mass GEM with zig-zag readout structures.
- **INFN Trieste**
  People: S. Dalla Torre, S. Dasgupta, G. Hamar, S. Levorato, F. Tessarotto
  R&D: Hybrid MPGD for RICH applications.
- **Stony Brook University (SBU)**
  People: K. Dehmelt, A. Deshpande, N. Feege, T. Hemmick
  R&D: Short radiator length RICH; Large mirror coating.
- **University Of Virginia (UVa)**
  People: K. Gnanvo, N. Liyanage
  R&D: Large & low mass GEM with u-v readout; Chromium-GEM (Cr-GEM).
- **Yale University**
  People: D. Majka, N. Smirnov
  R&D: 3-D-coordinate GEM readout; hybrid gain structure.

eRD6 / eRD3 Workshop at Temple Univ. May 20 – 21 / 2017

Schedule:

May 20 2 PM – 3:10 PM:

2:00 – 2:10	BNL	Future project interests/goals
2:10 – 2:20	INFN	"
2:20 – 2:30	Stony Brook	"
2:30 – 2:40	Yale	"
2:40 – 2:50	Temple	"
2:50 – 3:00	UVa	"
3:00 – 3:10	Florida Tech	"

3:10 PM – 6 PM: Impact on detector design from

3:10 – 4:30	Elke/Alexander/Yulia	Detector performance requirements
4:30 – 5:30	Elke/Yulia	Machine backgrounds (eRHIC/JLEIC)
5:30 – 6:00	All	Material budget

6 PM: Dinner downtown Philadelphia

May 21 9 AM – 12 PM: Impact on detector design from

9:00 – 9:30	Elke	Jet physics
9:30 – 10:00	Silvia	PID (RICH) – track matching
10:00 – 10:45	Tonko	Electronics, DAQ -> continuous readout
10:45 – 11:00		Coffee break
11:00 – 11:30	Oleg	Calorimetry
11:30 – 12:00	Leo	Vertex tracker

Noon – 1 PM: Lunch

1 PM – 5:30 PM:

1:00 – 2:00	All	Guidance from R&D results to machine groups
2:00 – 3:00	All	Priorities for detector R&D Decision tree
3:00 – 4:00	All	Priorities for detector R&D Open questions
4:00 – 4:15		Coffee break
4:15 – 5:30	All	Proposals for ACM in July

Regarding 2) f./g./h.: Tonko Ljubicic, Oleg Tsai, and Leo Greiner kindly agreed to dial in.

Yulia Furletova (JLEIC representative) kindly agreed to attend our meeting.

EIC Tracking and PID requirements

Rapidity Coverage:

tracking: $-4 < \eta < 4$
calorimetry: $-5 < \eta < 5$
π,K,p identification: $-3 < \eta < 3$

PID Requirements:

lepton / hadron separation strongly rapidity dependent
1:1 at $\eta < -1$ 10:1 to 10^3:1 at $-4<\eta<-1$ 10^4:1 at $-1<\eta<1$

π,K,p Identification:

π/(K,p) ratio ~3-4 → need high K efficiency and purity → positive ID
K/p ratio ~1
momentum-coverage:
$-3.5 < \eta < -1$: 0.1 GeV < p < 10 GeV → Aerogel RICH & dE/dx
$-1 < \eta < 1$: 0.1 GeV < p < 10 GeV → RICH & dE/dx
$1 < \eta < 3.5$: 0.1 GeV < p < 50 GeV → Dual radiator RICH & dE/dx

Momentum / Energy resolution:

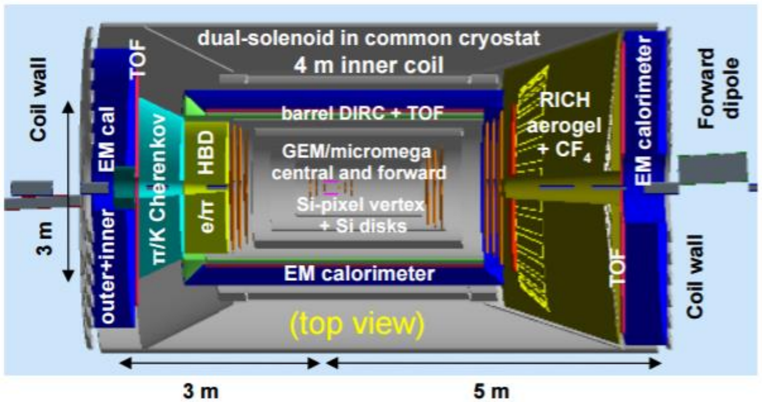
RICH in f/b rapidity: $\delta p/p$ < 1% p < 10 GeV $1<|\eta|<3.5$

Combined Calorimeter and Momentum resolution:

$$Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$ in x-Q^2 bins > 60% for 0.01<y<0.95

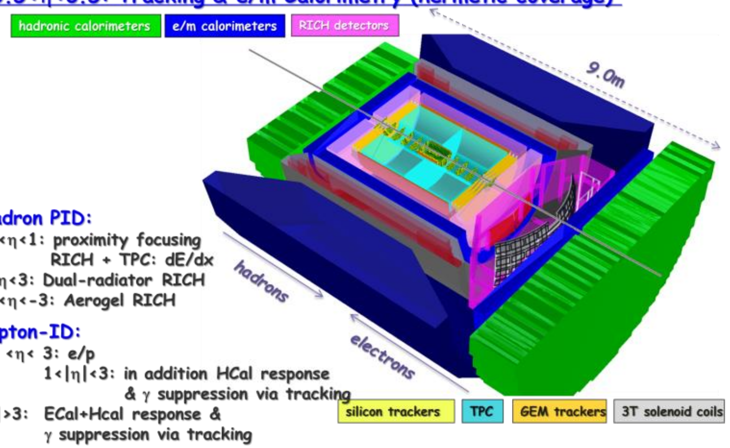
E.C Aschenauer
eRHIC Program Steering Group Meeting, June 2017

JLEIC Detector



BeAST

-3.5<η<3.5: Tracking & e/m Calorimetry (hermetic coverage)

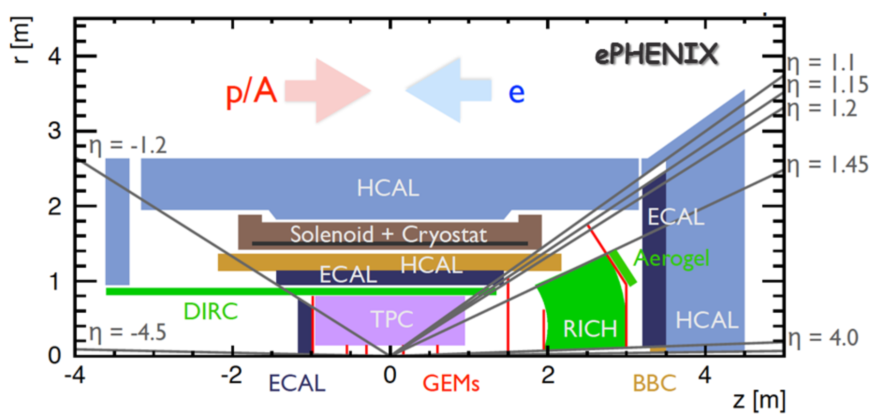


Hadron PID:
-1<η<1: proximity focusing RICH + TPC: dE/dx
1<η<3: Dual-radiator RICH
-1<η<-3: Aerogel RICH

Lepton-ID:
-3 <η< 3: e/p
1<|η|<3: in addition HCal response & γ suppression via tracking
|η|>3: ECal+Hcal response & γ suppression via tracking

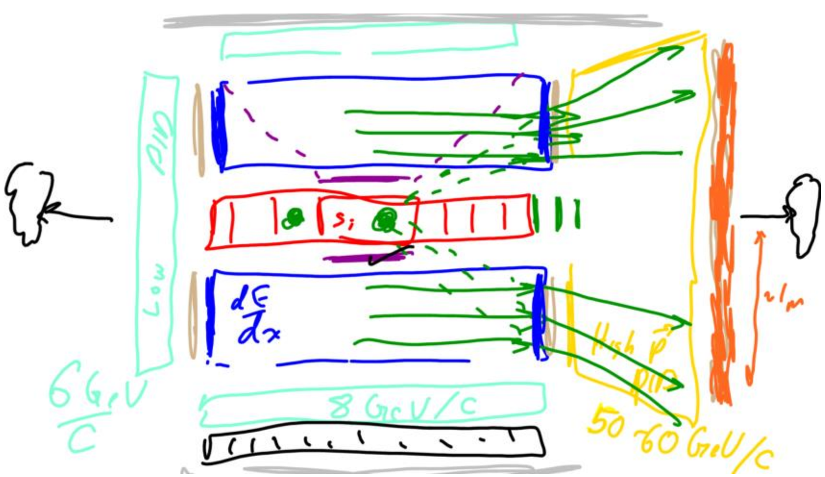
-4<η<4: Tracking (TPC+GEM+MAPS) MAPS: CMOS Monolithic Active Pixel Sensors

ePHENIX



eRD6 / eRD3 Workshop: Tailoring R&D to EIC Needs…

- The earliest EIC R&D efforts (eRD3, eRD6, …) are rapidly closing out their initial programs.
- Groups with gas-tracking interests held a meeting at Temple in May 2017:
  - Physics
  - Luminosity
  - Background
  - BeAST
  - Jlab-EIC
  - ePHENIX
  - Link to EMCAL
  - Link to SILICON
  - Link to PID
- New proposal guided specifically by updated EIC vision.



Hand-drawn consensus EIC detector design

Color	Name	Deliverable	Favored Tech	Comment
Red	Silicon Pixels	Displaced Vertex	MAPS	Must be thinnest technology to remain consistent with soft electrons
Blue*,**	Volume Tracker	dE/dx, pattern recognition	TPC* or straws, Timepix**	R&D will pursue and determine viability of using reconfigured sPHENIX TPC
Purple*,**	Single Event Barrel Tagger	Single event response, momentum resolution	μRWELL*, μMEGAS**	μRWELL in eRD6, μMEGAS w/in eRD3 goals.
Brown*	Fast Endcap Tagger	Single event response, track stub.	Mini-drift GEM detector	Alteration to ongoing development, yields beampipe region to silicon.
Green*	Forward Tagger	Single event response, patt. recognition at extremely low mass	Chromium GEMs	Interstitial layers between MAPS devices with even less
Gold*	High mom. RICH	PID up to 50 GeV/c	COMPASS RICH Technology	Investigate new possibilities with diamond powder cathodes.
Orange**	RICH Seed Tagger	Seed point for RICH, eID for J/ψ	TRD**	Pursued under different cover.

* Asterisk superscripts indicate the items consistent with the eRD6 past and/or proposed R&D efforts
** The Double-asterisks indicate the research topics whose funding request is made under a separate request with additional collaborators from Saclay (μMEGAS) or J-Lab (TRD).

eRD6 Consortium: What was achieved the past period

- **Brookhaven National Laboratory (BNL)**
  - Optimization of the zigzag pad readout pattern parameters, fabrication of PCB with this readout pattern and measurement of the relative position resolution in the lab
  - Refining the analysis of the beam test results from TPC-C prototype, ***(in collaboration with SBU)***
  - Draft paper for submission to IEEE TNS
  - Initial results from TPC gas studies
- **Florida Institute Of Technology (FIT)**
  - Inspection of the zigzag structure under a microscope of large readout board and HV test of the common GEM foil
  - In-home production of the outer carbon fiber frames completed and mechanically tested and validated
  - Manuscript on the performance of improved zigzag structures in preparation for NIM A
- **INFN Trieste**
  - Test of novel materials for the THGEM PCB
  - Development of resistive MM by discrete elements with miniaturized pad size
- **Stony Brook University (SBU)**
  - Procurement of all needed equipment for the upgrade of existing CsI evaporator
  - Preparation of the evaporation equipment to be installed into the evaporator
- **University Of Virginia (UVa)**
  - Aging test of Cr-GEM with x-ray and validation of double zebra connection scheme on small GEM prototype
  - Finalize large U-V strips readout and zebra connection and support frame design.
  - Production of the board and the zebra connection pieces is ongoing at CERN.
- **Yale University**
  - Hybrid Gain Structure for TPC read-out – 2 GEMs plus Micromegas (2-GEMs + MMG).
  - Multi-element stacked gated grid

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eRD6 Consortium: Funding request for the coming cycle

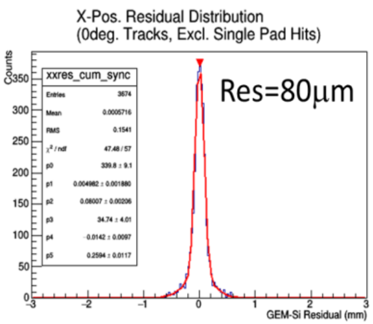
- **Brookhaven National Laboratory (BNL):**
  - Continue zigzag pad development **(critical for EIC)**, setup of GEM-based cosmic ray telescope
  - **GEM Studies using TPC gas mixtures, collaborate with Stony Brook group, (critical for EIC)**
- **INFN Trieste**
  - Complete the studies of novel materials for the THGEM PCB and the development of resistive MM with miniaturized pad size
  - **New proposal: Exploration of new photocathode based on NanoDiamond (ND) particles (critical for EIC)**
- **Stony Brook University (SBU)**
  - **New proposal: Ion flow back studies (critical for EIC)**
- **Joint UVa & Florida Tech proposal**
  - Assembly of large low mass GEM prototypes (u-v and zigzag strips readout), characterization at Fermilab Test Beam Facility.
  - Development of Large area Chromium GEM (Cr-GEM), simulation and prototyping
  - **New proposal: Development of cylindrical μ-RWELL for fast hit information in the central tracking (critical for EIC)**

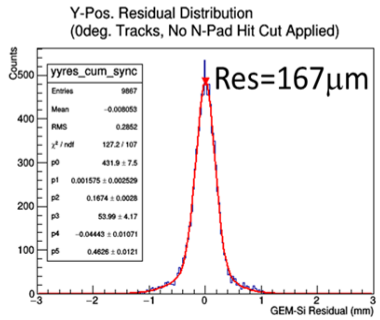
Cost matrix

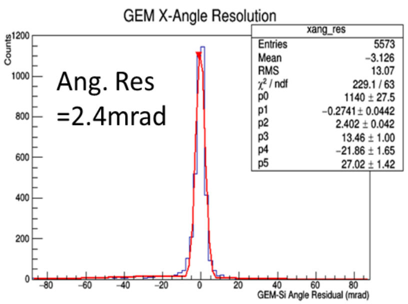
$k	THGEM	Zig-Zag Pads	TPC Gas Choice	μ-RWELL Studies	Chromium GEM Foils	Test Beam (lg chamb)	Ion Back Flow	TOTAL
BNL		63.0	12.0					**75**
Stony Brook							42.0	**42**
UVA				7.0		8.25		**15.25**
FIT				7.0	4.0	6.75		**17.75**
INFN	**50**							**50**
TOTAL	**50**	**63**	**12**	**14**	**4**	**15**	**42**	**200**

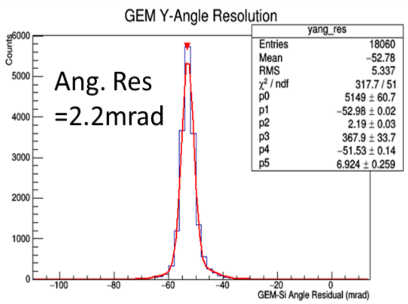
Progress @ BNL: TPC-Cherenkov Prototype

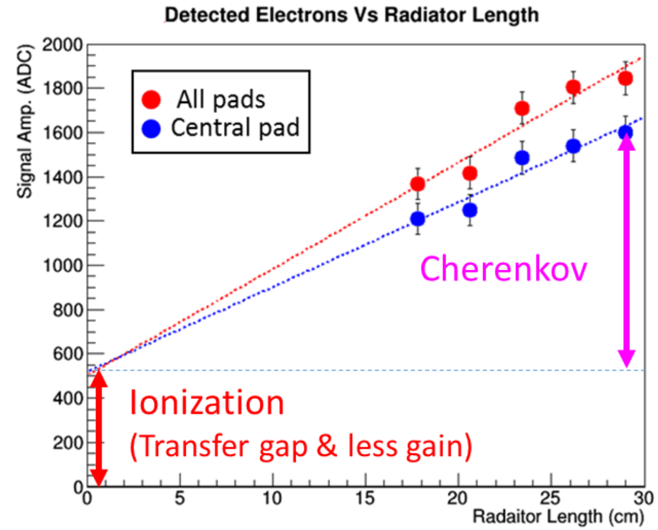
(Collaboration with SBU)

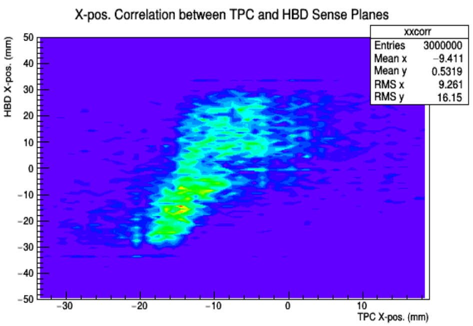


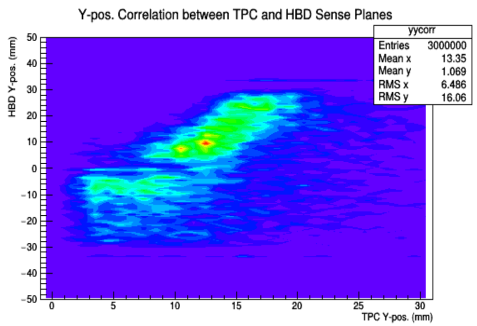


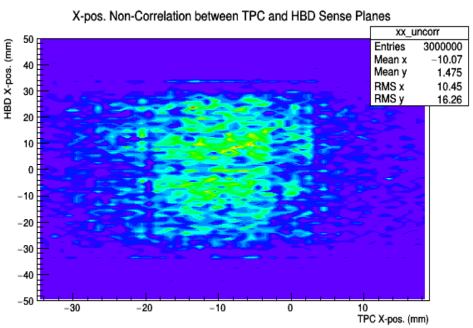


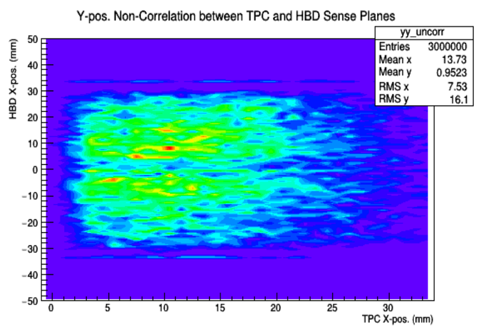








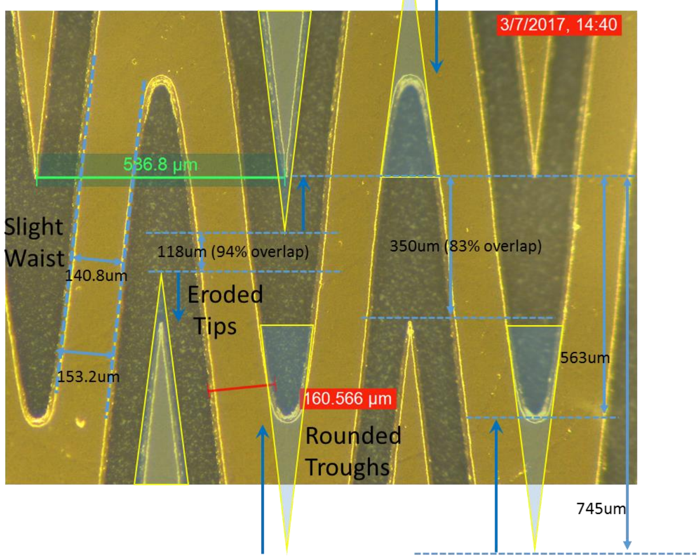


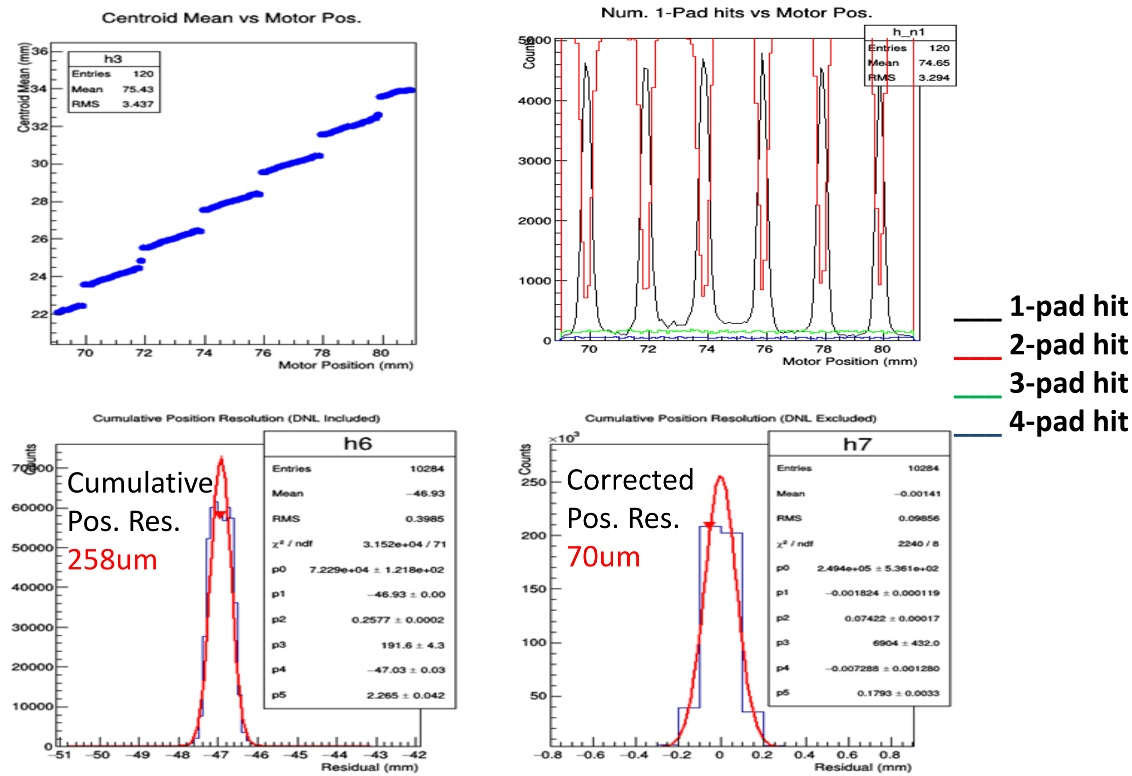


- The TPC Position and angular resolutions look very good for a 10 cm drift length and 10 pad rows of readout
- The Cherenkov detector radiator length scan shows a linear response w.r.t. the Cherenkov signal, and the absolute number of photoelectrons at 29 cm (~11pe) is in reasonable agreement with expectations (~12)
- Strong position correlation between TPC and Cherenkov observed

Progress @ BNL: New Zigzag readout

Zoomed in Microscope image of recent Zigzag PCB produced by Somacis



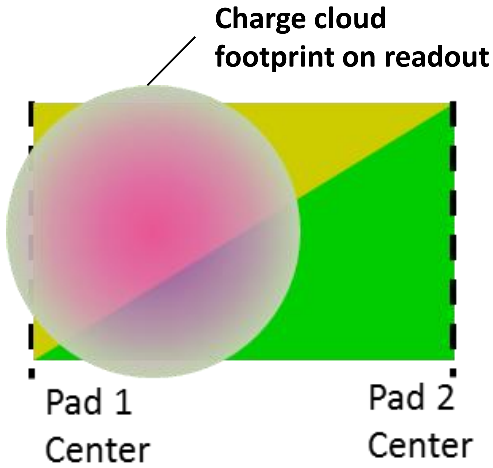


Distortions of zigzag geometry

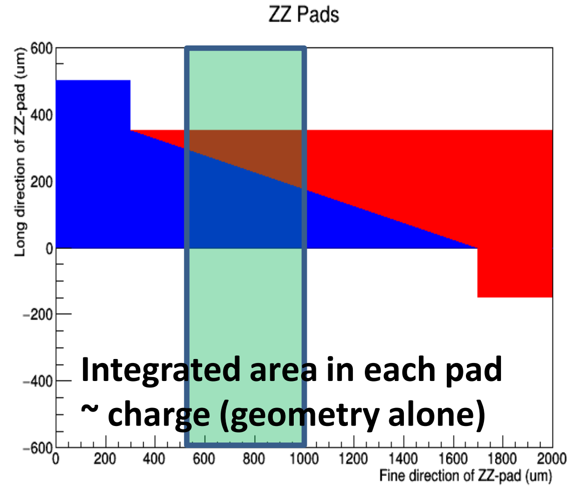
- **Over-etched tips (overlap=94%(design) vs 82%(actual) →reduction in charge sharing**
- **Over-etched trace width (copper coverage= 67%(design) vs 63% (actual) →larger field distortions (non-linear effects)**
- **Under-etched troughs → non-linear effects**

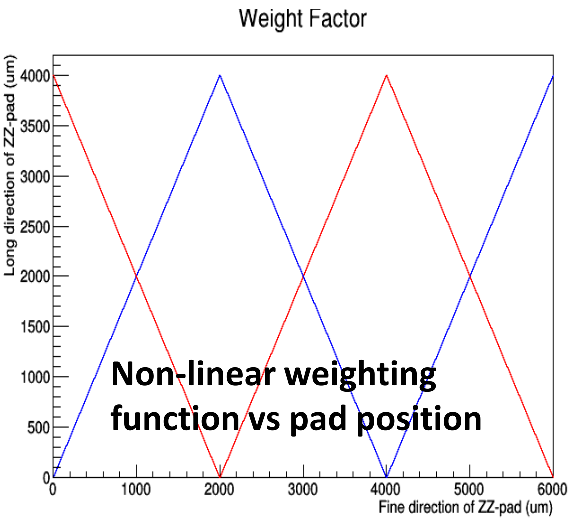
- Piece-wise linear correlation betwen actual and reconstructed position, with constant slope ~1/2
- Global position resolution after correcting for piece-wise slope = 70um
- Still suffer from single pad hits in regions near center of pad (due to low gain, non-optimal interleaving, small transverse diffusion, etc)
- Needs further improvement!

Progress @ BNL: Zigzag linear charge sharing model

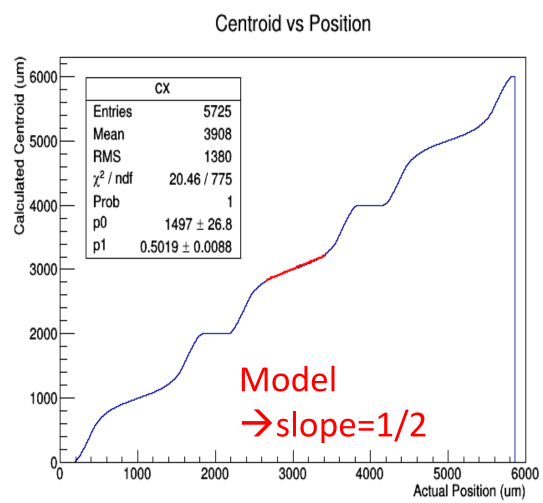


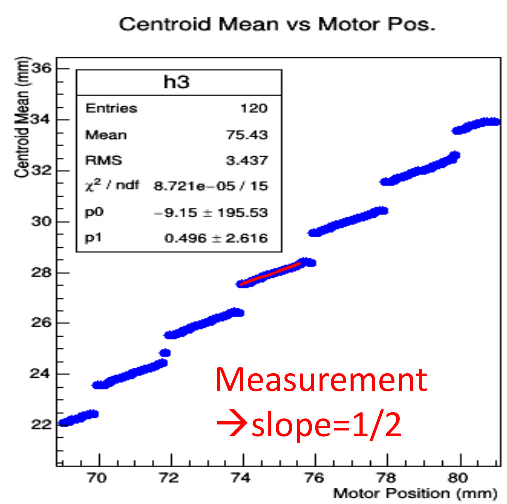
Charge sharing between two pads

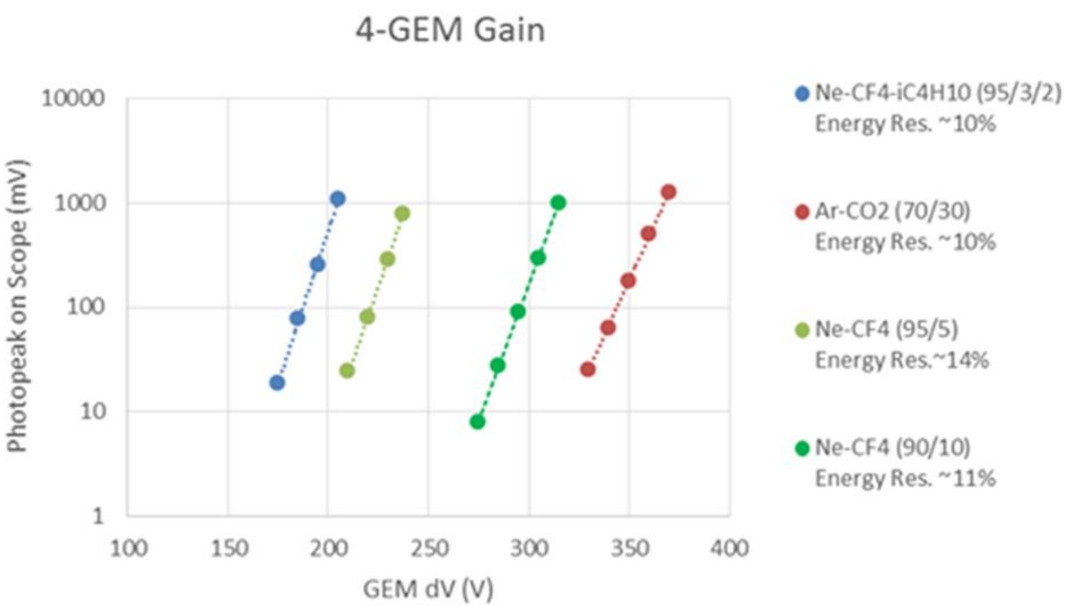


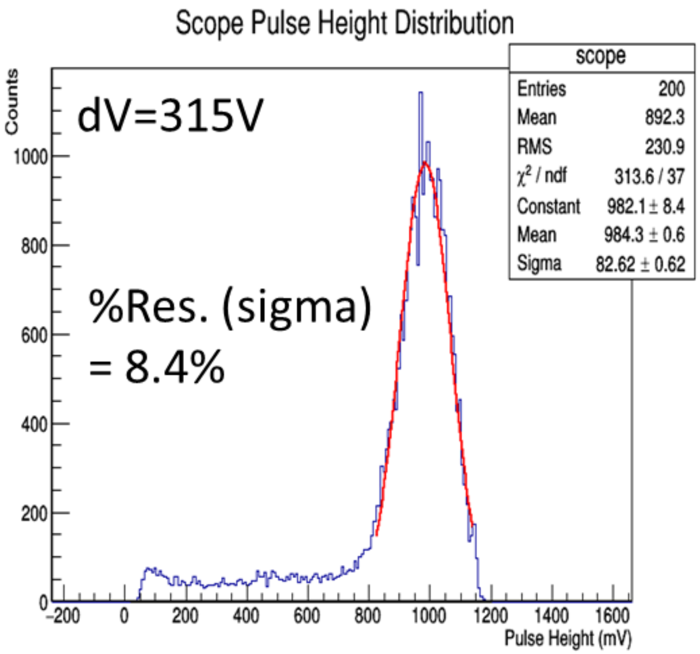


- Based on geometry alone, charge sharing should be linear w.r.t hit position
- However, data shows a piece-wise linear relation, with a slope of ~1/2
- We apply a naïve ad-hoc weighting function so that that the simulated results match the observed ones
- Perhaps the weighting represents the non-linear effects of the local electric field on charge collection
- Will continue developing more sophisticated simulations to explain the fundamentals of charge sharing





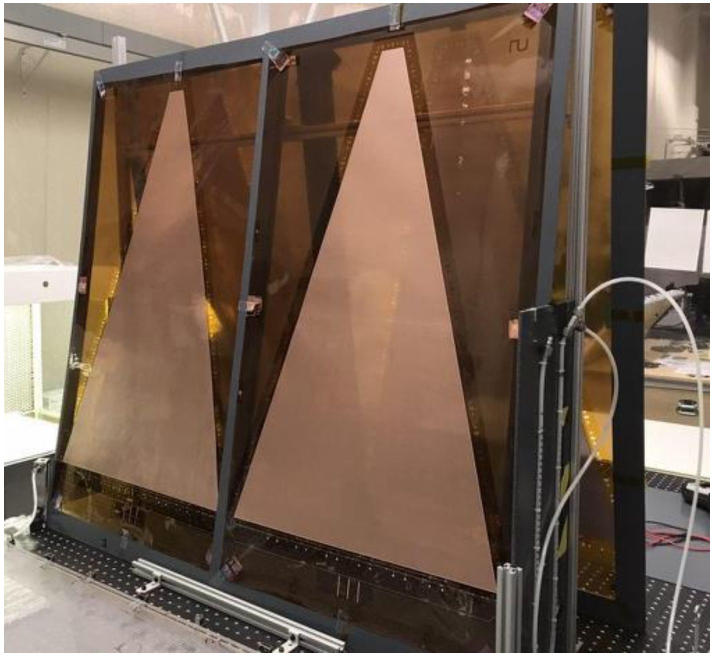


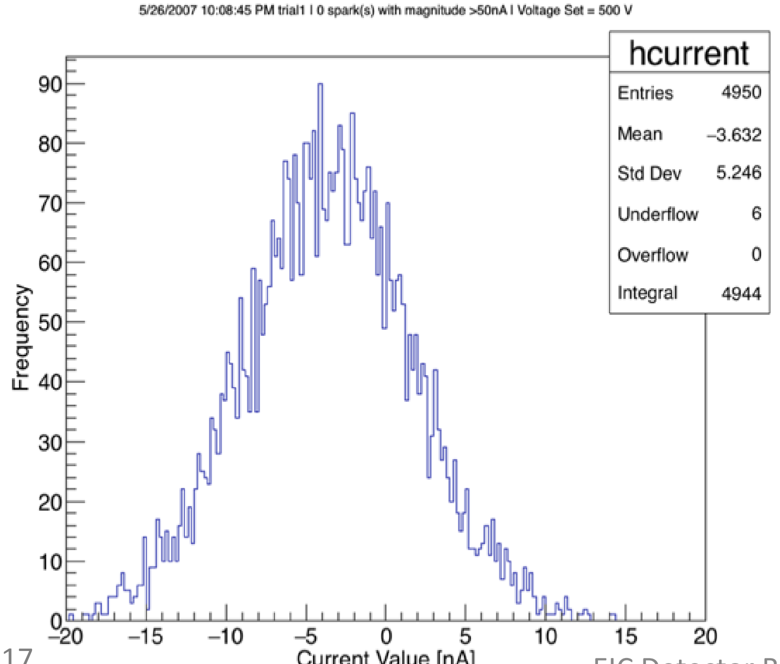


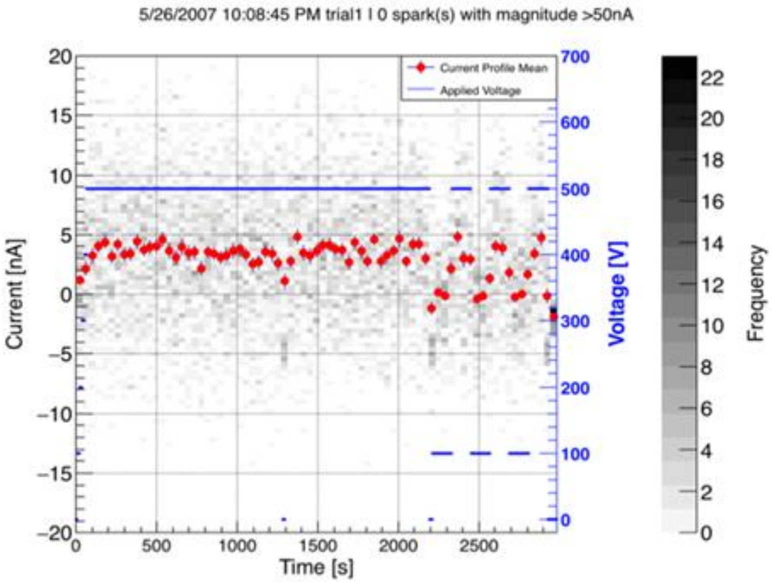
Gain comparison of candidate TPC gases, in addition to the energy resolution for $NeCF_4$ (90/10)

Progress @ FIT: Large Forward GEM Tracker Prototype

- Tests of the large-area common GEM foils: all four foils were tested to be good.
- Leakage current < 5 nA @ 500 Volts across foils (in N2 gas).

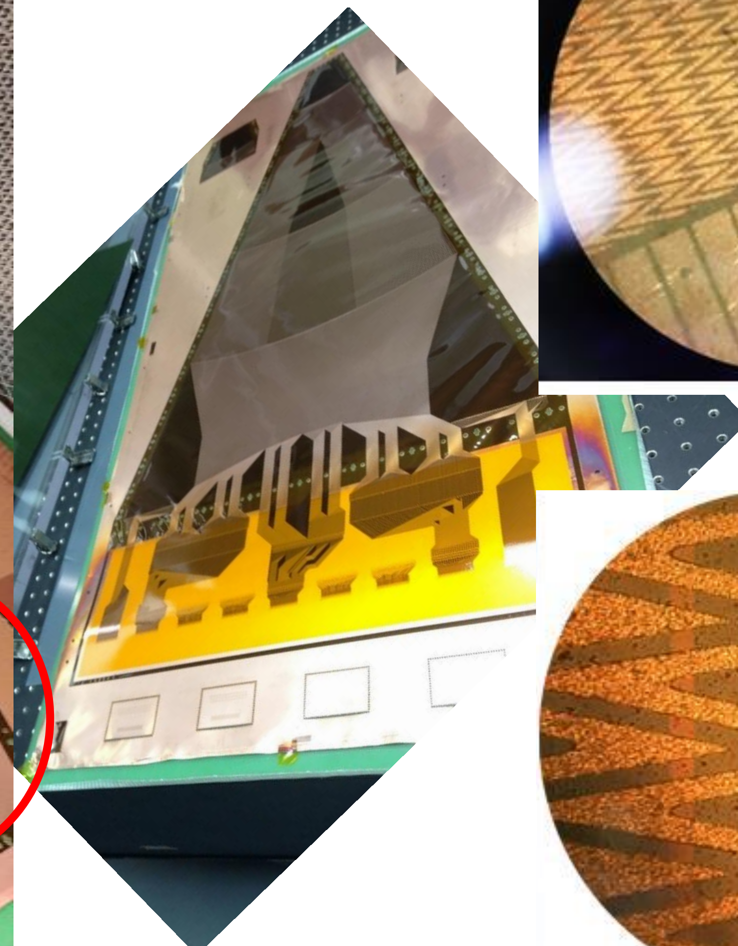


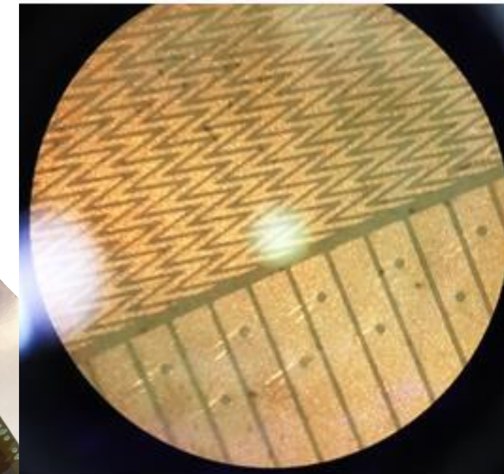


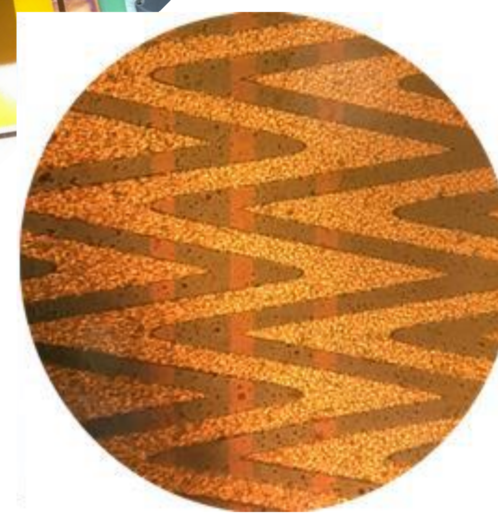


Progress @ FIT: Large Forward GEM Tracker Prototype

- Quality check of the large zigzag readout





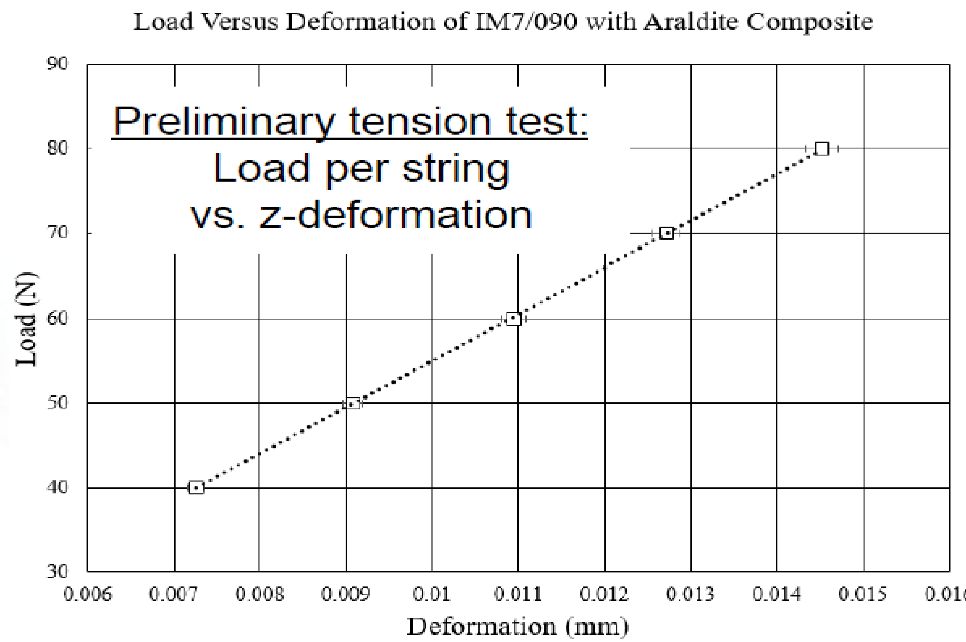


The readout foil looks OK after careful checking!

Progress @ FIT: Large Forward GEM Tracker Prototype

- In-house production of carbon fiber frames for supporting stretching forces when assembling the detector

Carbon Fiber Composite:
- Araldite epoxy (AY103)
- Intermediate-modulus uni-directional carbon fiber ("IM7")
- 8 layers of CF each; ~ 4mm thick
- Produced in-house
- <1 mm (~0.01%) deformation under the stretching of five foils is achievable.



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Progress @ INFN Trieste: MPGD-based Photon Detector for high momentum RICHes

- h-PID in the range 6 < p < 60 GeV/c, a must for experiments @ EIC
  - At high momenta: **gas radiator** is mandatory
  - Collider implementation: **short** (~ 1 m) **radiator length**
  - Two attempts, so far, both requiring deeper exploration
    - ✓ High pressure, studied for ALICE upgrade VHMPID
    - ✓ Towards the very far UV with window-less approach (prototype tested at Fermilab)
    - ✓ In both approaches gaseous photon detectors are mandatory

- R&D program
  - Further development of MPGD-based Photon Detectors
    1. Miniaturized pads
    2. Operation in C-F gasses
    3. THGEM vs GEM for optimal photoelectron collection
    4. Ion BackFlow (IBF) control
    5. NEW: photocathodes alternative to CsI

    ✓ 1), 4) synergic with R&D for high rate TPCs

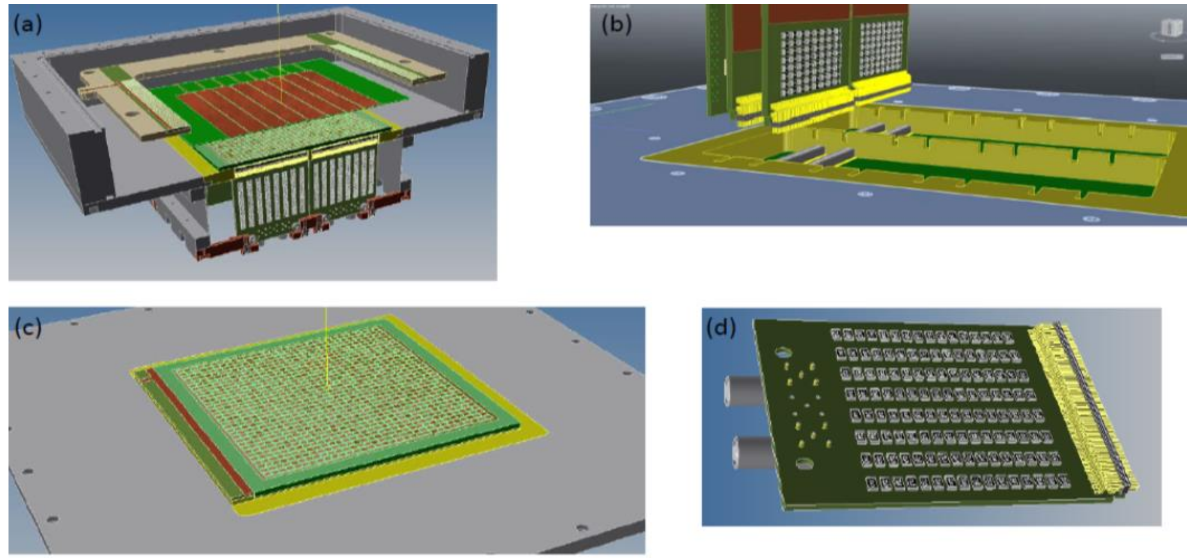
Progress @ INFN Trieste: MPGD-based Photon Detector with miniaturized pads

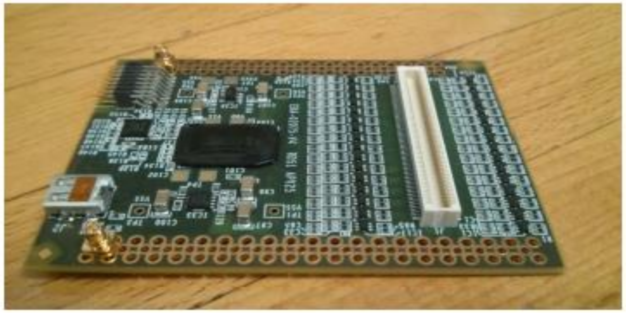
ACTIVITY STARTED Jan. 2017,

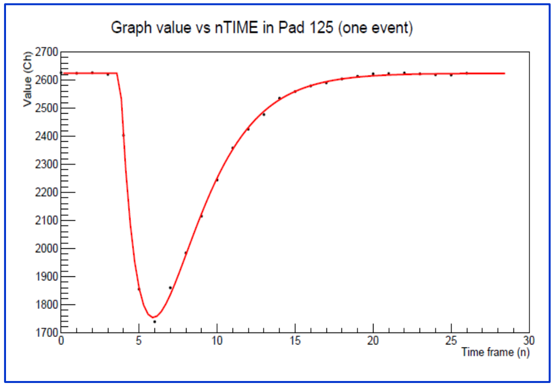
ongoing

- Design of a prototype of the resistive MM by discrete elements with miniaturized pad-size well advanced

- Preparing the DAQ to characterize the prototype







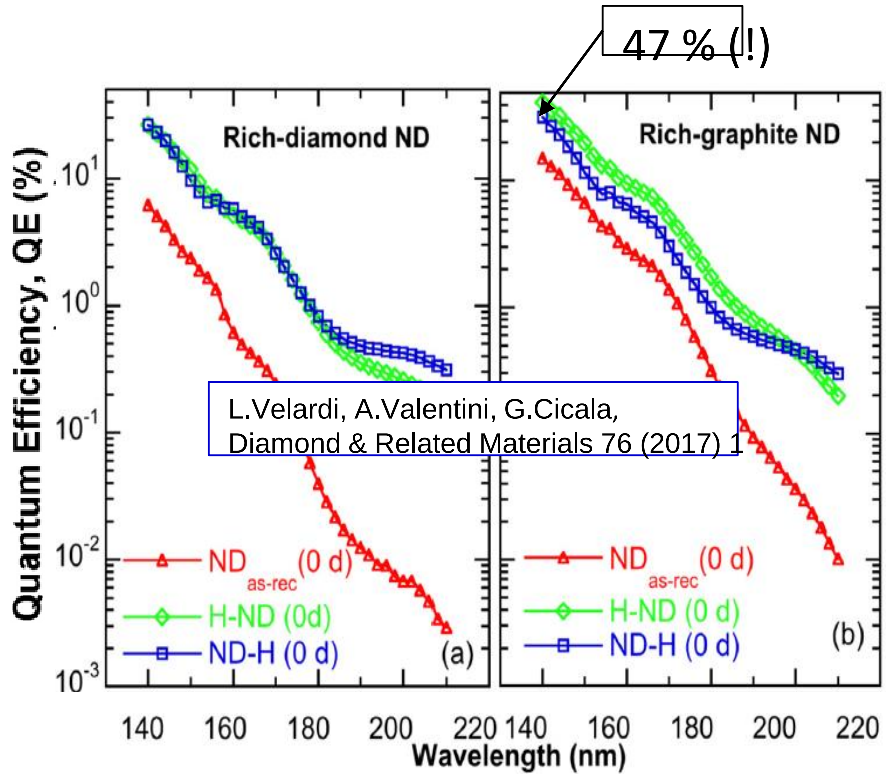
Collecting data with 1 APV

From 100 hz maximum up to 6 khz only using the right settings.

Progress @ INFN Trieste: Towards innovative photocathodes

CsI, the only standard photoconverter compatible with gaseous atmospheres, has problematic issues, main ones:

- *It does **not** tolerate **exposure to air** (water vapour, O_2)*
- ***Ageing** by ion bombardment*



From Antonio Valentini – INFN - Bari

- ***Photocatodes: diamon film obtained with***
  - ***Spray Technique making use of NC (NanoCrystals) powder***
  - ***Spray technique: T ~ 120° (instead of >800° as in standard techniques)***

Coupling of ND photoconverter and MPGDs: answering a first set of basic questions

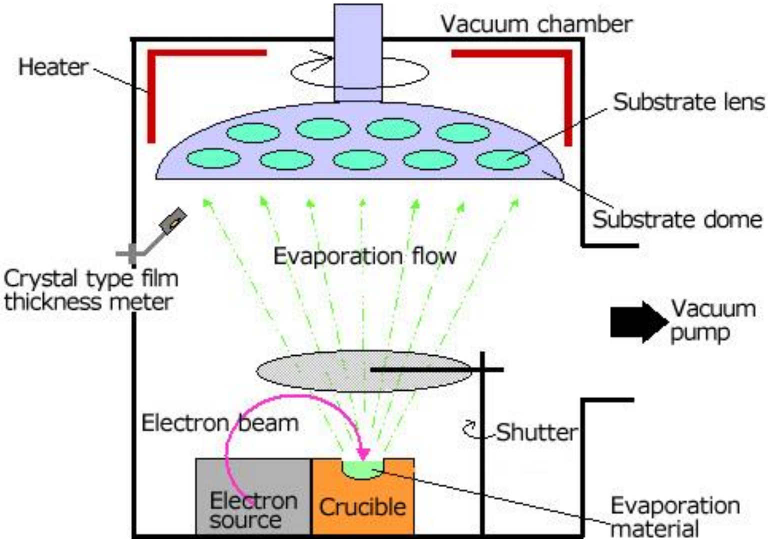
- QE: gas vs vacuum?
- Characterize a prototype
- Ageing ?

NEW !

Proposed for 2018

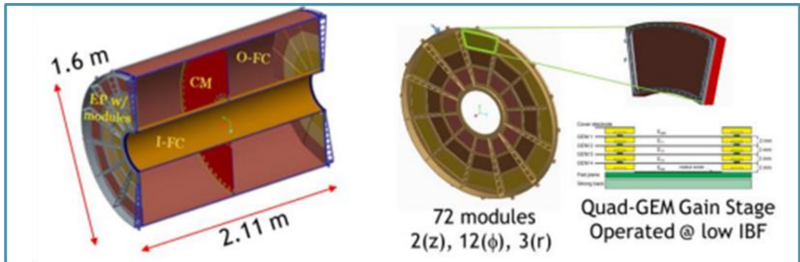
Progress @ SBU: Preparation of “INFN evaporator” for large mirror coating

Ion beam setup



- We have acquired
  - Electron gun
  - Ion gun
  - Power supplies
  - Thickness monitors
  - Ion gun → smoothen surface
    - Coating to be ~ hundreds of Å , controlled to the level of ~ tens of Å → “hammer” bumps away
- We will acquire
  - Mirror mounting structure

Progress @ SBU: Is space charge an issue for EIC?



Question: Is the sPHENIX TPC reusable @ EIC?

- Consensus without calculation:
  - No it is not an issue.
  - If sPHENIX TPC works, EIC is easier.
- sPHENIX optimization for heavy ions inappropriate for EIC.
  - sPHENIX emphasizes position resolution and low Ion Back Flow at a loss of dE/dx resolution.
  - EIC requires dE/dx as the principal deliverable of the TPC.
- Quantitative comparison of sPHENIX and EIC:

	AuAu 200 Gev	EIC (baseline)	EIC (Ultimate)
Gas	Neon	Argon	Argon
Ionization (e/cm)	43	94	94
Multiplicity	450	0.45	0.45
Rate	100	69	711
K	6.93	1.96	1.96
Dead Volume Factor	0.1	1	1
Op Point Factor	0.3	2	2
FOM	8377	2978	30689
FOM relative to sPHENIX	1.00	0.36	3.66

dE/dx requires higher ionization density

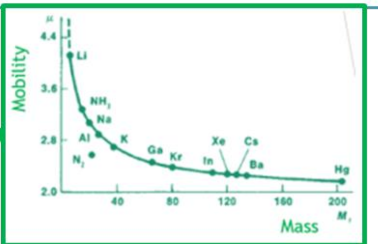
Machine Conditions

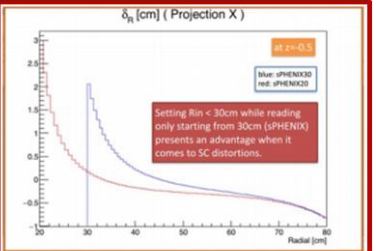
Positive Ion Mobility

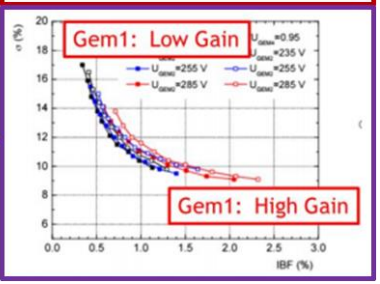
EIC-TPC cannot ignore tracks @ r<30 cm.

EIC must operate avalanche w/ good dE/dx resol!

After optimizing for dE/dx; EIC-TPC space charge is challenging!



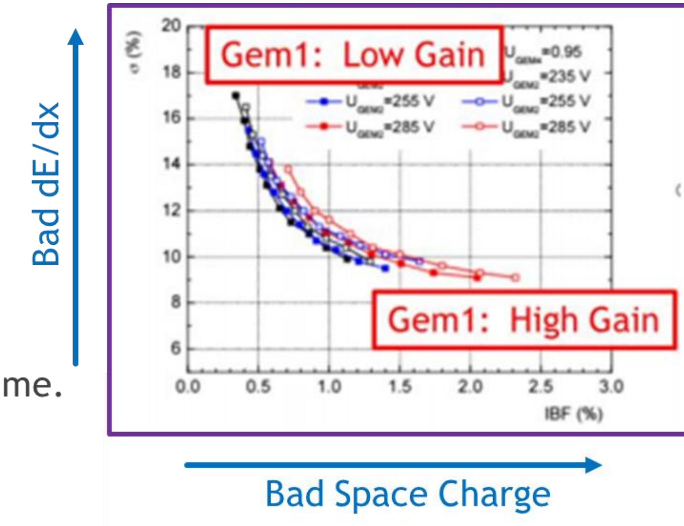




Progress @ SBU: Concept: Passive IBF grid.

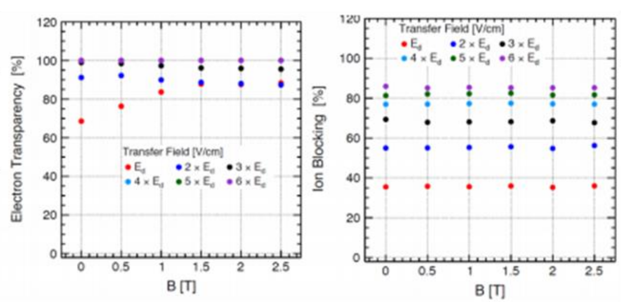
NEW ! Proposal for 2018

- Questions:
  - What drives the “Universal” IBF curve?
  - Can we do better?
- In ALICE mode, the 1st GEM is coupled DIRECTLY to the TPC volume.
- Ions produced in the 1st avalanche stage are coupled directly into volume.
  - High gain in the 1st GEM means large IBF.
  - Low gain in the 1st GEM means large gain fluctuations.
- New concepts:
  - Mesh with asymmetric entrance/exit field:
    - Transparency near 100% preserves dE/dx resolution.
    - Imposes additional positive ion shielding.



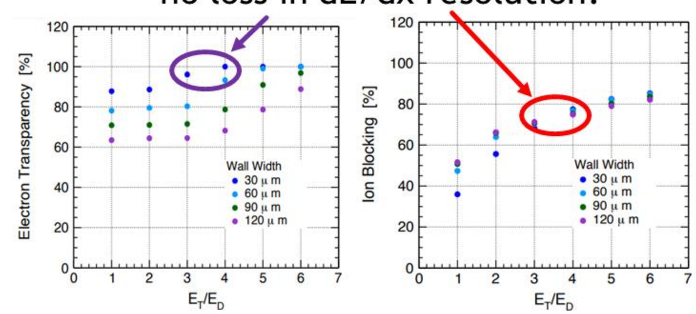
R&D program will fully optimize the IBF grid design for the EIC-TPC.

Perfect e-Transmission



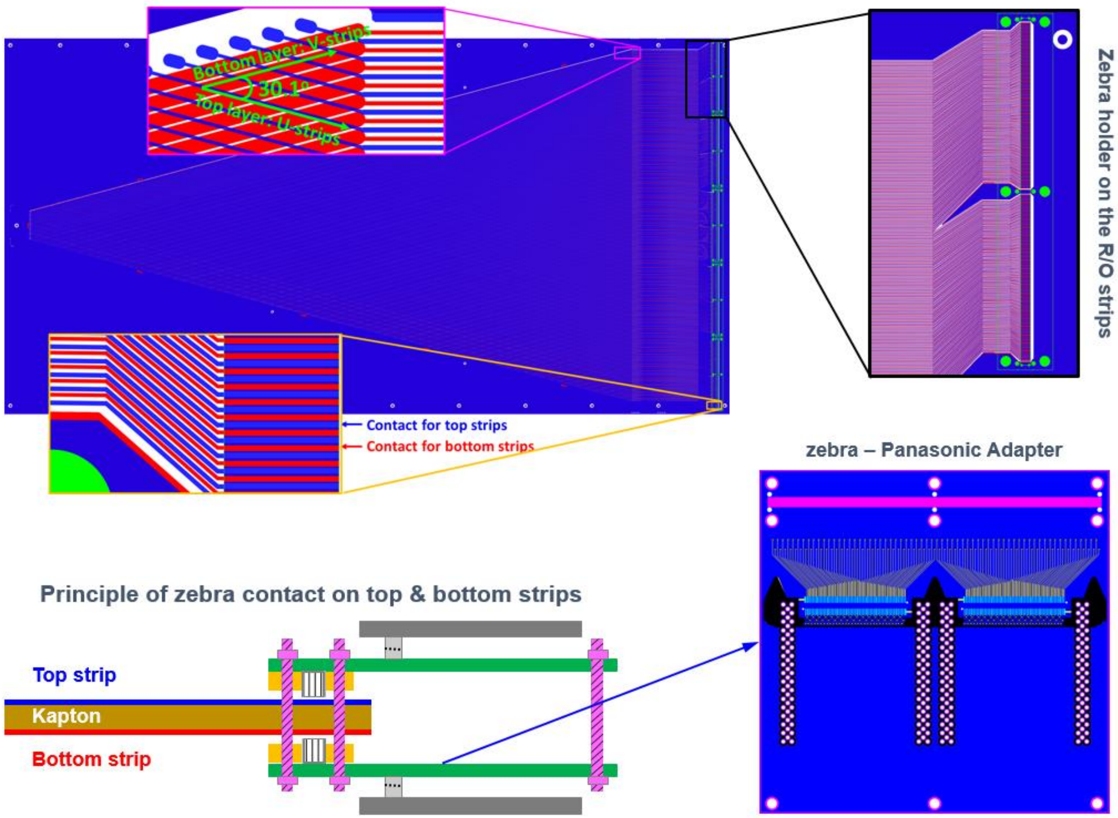
Perfect Ion-Blocking

Possible 4-5X IBF reduction with ~no loss in dE/dx resolution!



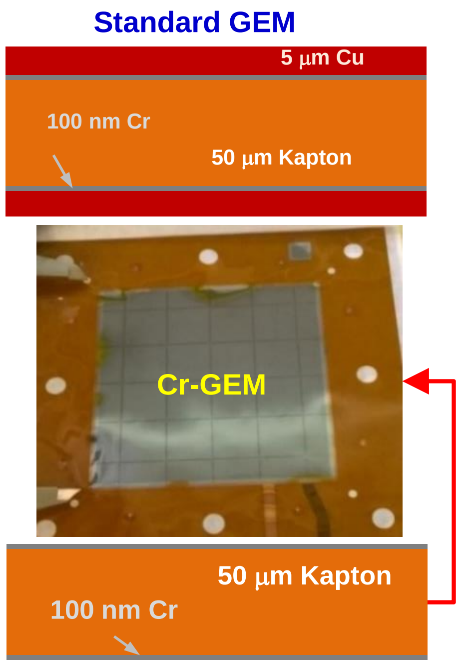
Progress @ UVa: Large Forward GEM Tracker Prototype

2D U-V strip readout and Zebra connection principle



- ❖ **Development of large U-V strip readout**
  - Principle of double side zebra connection fully and successfully tested on small prototype
  - Design for the large U-V strip readout completed
  - All parts in production at CERN (delivery expected end August)
- ❖ **Design of GEM supporting frames completed**
  - Completed the design for the GEM supports frames
  - Two set of frames developed for cost saving
    - ⇨ PERMAGLAS with 300 um spacer grid frames for the GEM foils (high cost)
    - ⇨ Low cost with standard G10 for outer frames i.e. gas windows (low cost)
  - Two set of frames developed for cost saving
- ❖ **Completion of the large GEM with U-V readout R&D**
  - Assembly the prototype and test with cosmic at UVa
  - Fermilab Test beam for full characterization of spatial resolution, gain uniformity etc ..
  - Manuscript on final results to be submitted to TNS or NIMA

Progress @ UVa: Results of the aging test of Cr-GEM with x-ray



❖ Measurement of the gain ratio between standard GEM and Cr-GEM

- Same setup for the test and same condition
- Ratio cancels out gain variation with temperature and pressure

❖ Low gain condition: equivalent MIP gain ~ 5 × 104

- From day 1 to day 35, Daily accumulated charges = **4 mC / day ⇨ 40 μC/cm^2**
- Stable gain ratio: **no degradation of the gain, efficiency no apparition of dead area**

❖ High gain condition: equivalent MIP gain ~ 5 × 10^4

- From day 35 to day 65, daily accumulated charges = **30 mC / day ⇨ 300 μC/cm^2**
- Slow but steady decline of the gain ratio ⇨ **No effect on efficiency and no dead area**

❖ **Study ongoing to understand this effect**

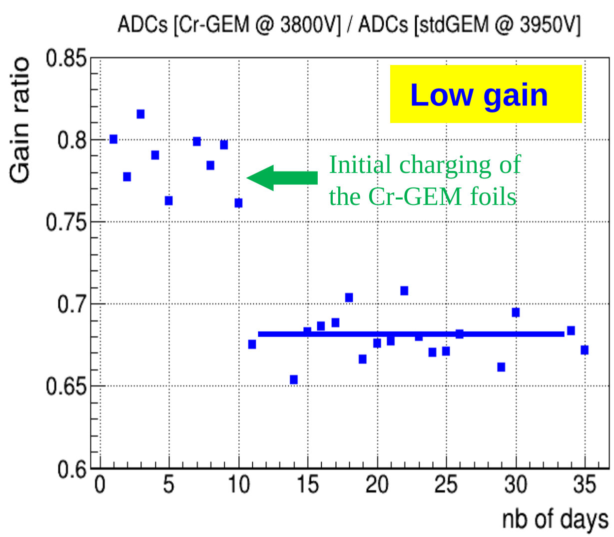
X-ray experimental setup:

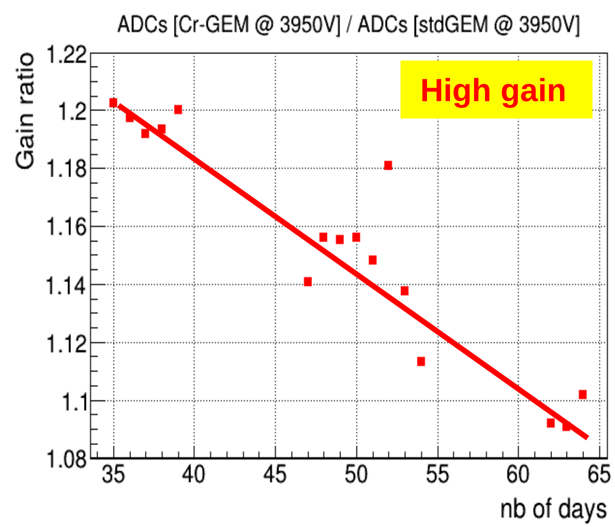
- HV @ 15 V, I @ 50 μA, 65 days run
- Two small GEM: Cr-GEM and standard GEM (used as reference)

Test conditions: two gain regime

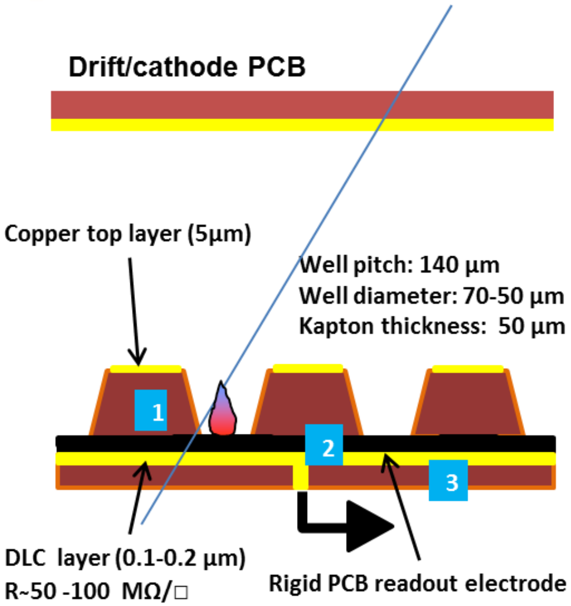
⇨ Low gain @ 3800 V, gain ~ 1000 (equiv. ~ 10^4 with MIP)

⇨ High gain @ 3950 V, Gain ~ 5000 (equiv. ~ 5 × 10^4 with MIP)





UVa & FIT joint proposal: Development of large cylindrical μ-RWELL



μ-RWELL PCB

G. Bencivenni et al., 2015_JINST_10_P02008

The μ-RWELL_PCB is realized by coupling:

1. a “suitable WELL patterned kapton foil as “amplification stage”
2. a “resistive stage” for the discharge suppression & current evacuation:
3. a standard readout PCB

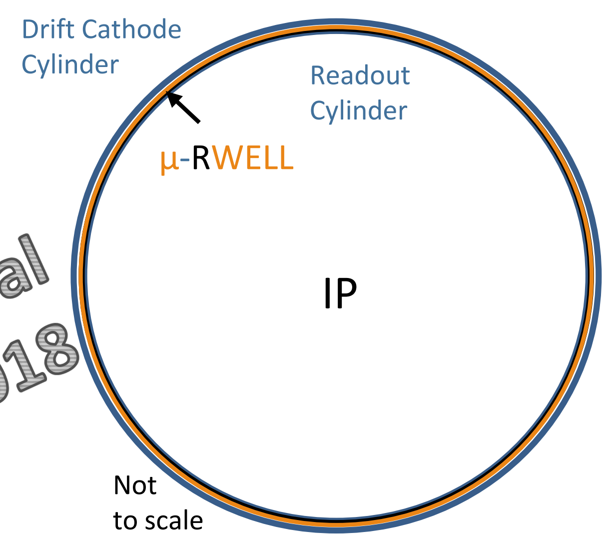
Combines the advantages of both GEMs & Micromegas

- Like Micromegas ⇨ single amplification stage, thin structure, low material
- Like GEM ⇨ Simple & single structure ⇨ just like GEM foil
- Unlike GEM and µMegas, ⇨ no stretching, flexible or rigid PCB
- Low cost MPGD detector

Cylindrical μ-RWELL in the central EIC tracking detector

- Fast hit information for the EIC detector conceptual design
- Low cost and simpler alternative technology to µMegas
- Main challenge is the large area cylindrical detector
- Development of appropriate readout scheme
  - ⇨ Florida Tech zigzag readout and UVa 2D readout will be investigated for μ-RWELL

NEW ! Proposal for 2018



Progress @ Yale: Performance comparison for two TPC readout options

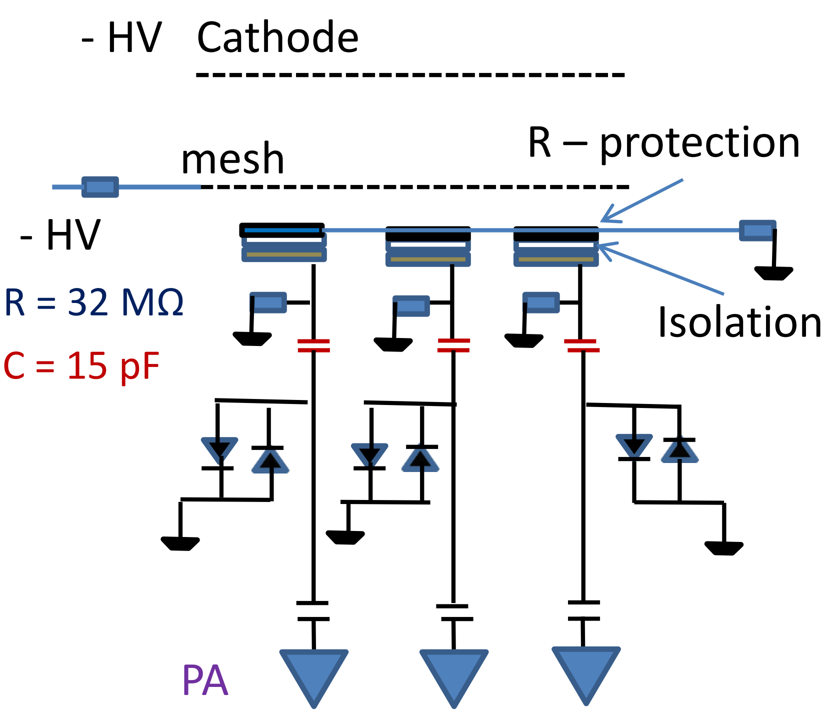
IBF – E-resolution – Stability

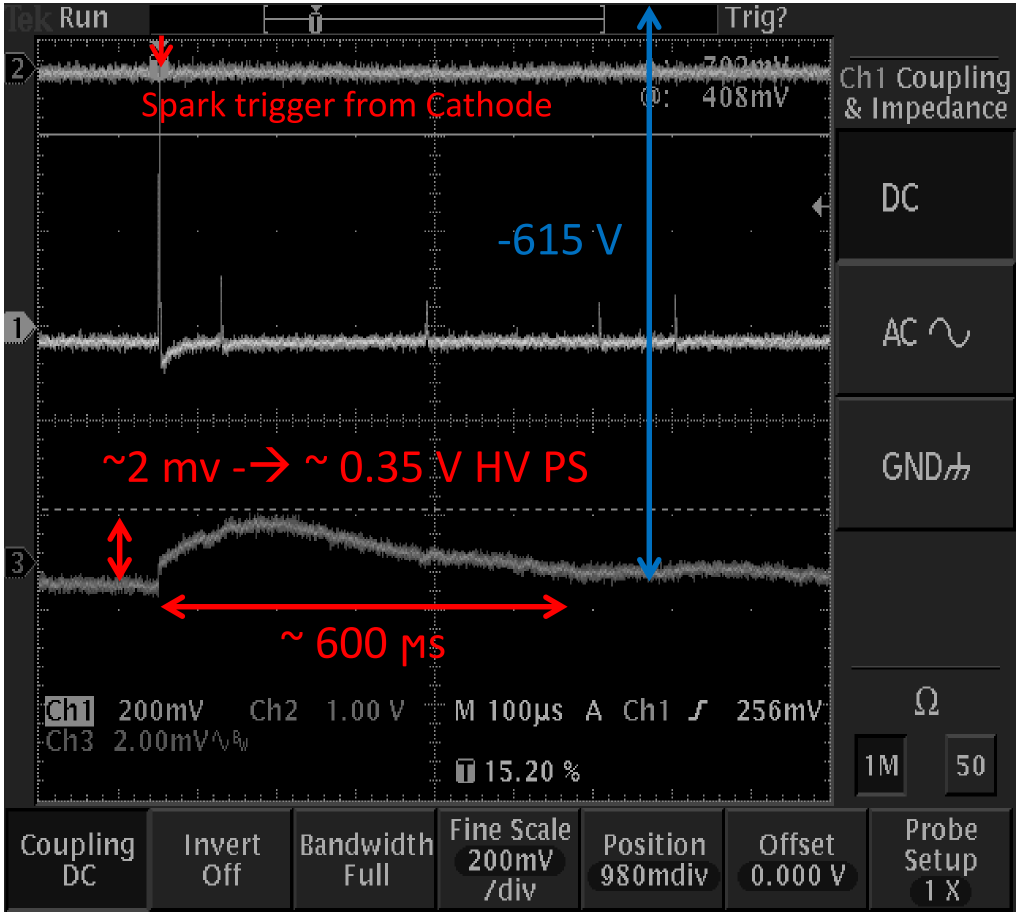
	4 GEMs	2 GEMs + MMG (no R-layer)
IBF (E drift: 0.4 kV/cm)	(0.6 - 0.7)%	(0.3 – 0.4)%
<GA>	2000	2000
ϵ - parameter	12 - 14	6 - 8
E – resolution	<12%	<12%
Gas Mixture (3 components)	Ne+CO2+N2 (Et “problem” with + CF4)	Ne+CO2+N2, Ne+CO2, Ne+CF4, Ne+CO2+CH4
Discharges (Am241) Discharges, SPS test-beam Ne+CO2+N2 Possible main problem	<3.*10 $^{-9}$ ~6.4*10 $^{-12}$ short sector of the foil	< 3.*10 $^{-7}$ (Ne+CO2) < 2.*10 $^{-8}$ (Ne+CO2+C2H4) ~ 3.5*10 $^{-10}$ Extreme robust. But number of hits And HV “recovery” time.
Pad structure	Any, but improvement with Chevron	Not Chevron Cross-talk effect
“General”	4 unique GEM foils/chamber IBF = F(X,Y), 20-30% variation HV > 3.5 kV. The same V on all tot GEMs (TPC drift field)	Minimize all these problem (Possible) reduce the cost.

Progress @ Yale: Performance comparison for two TPC readout options

The MMG setup with Resistive layers (strips) protection (1. MΩ / □),
its own for each pad-row.
V Mesh = - 615 V. Discharge rate: ~ 1/20 s

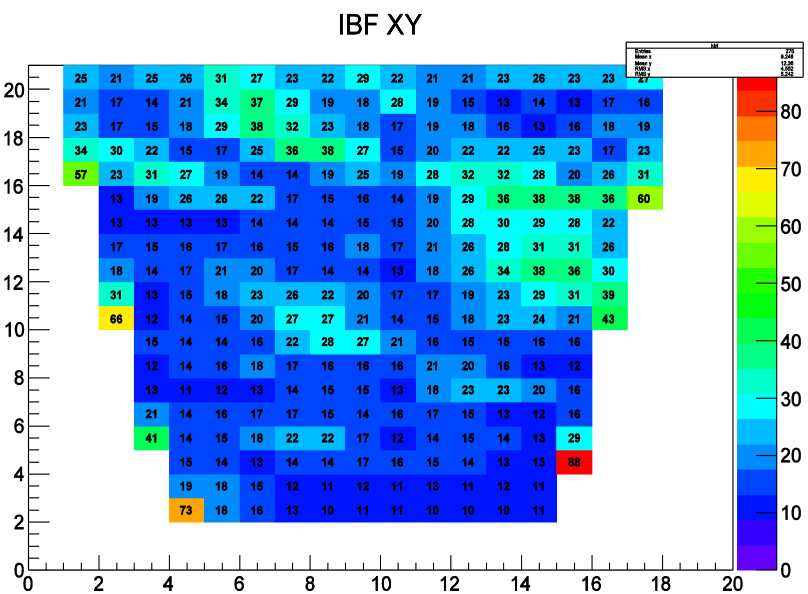
HV drop: ~ 0.4 V, Recovery time: ~ 600 µs *)
Discharges are "invisible" from HV PS voltage drop point of view

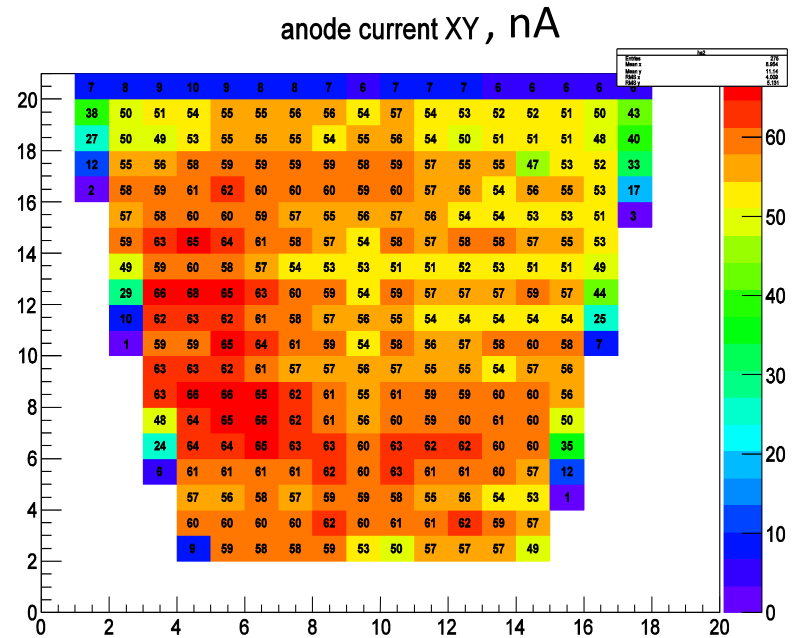




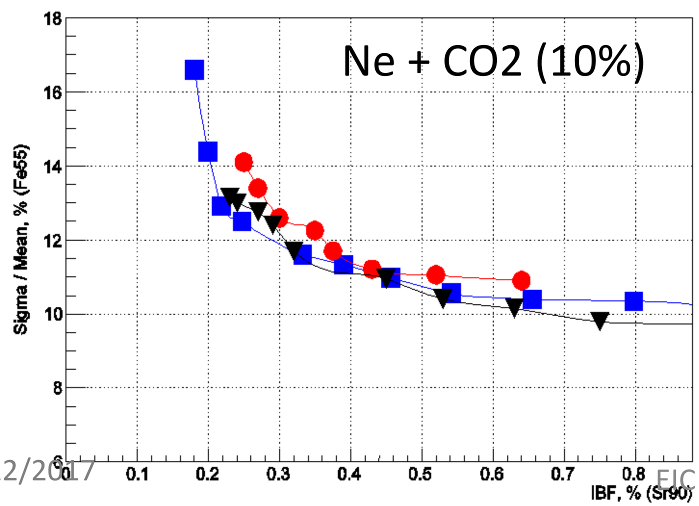
Progress @ Yale: Performance comparison for two TPC readout options

Standard MMG+2 GEMs (not rotated foils) setup, IROC ALICE TPC size ("HIROC")
X-ray gun X,Y scan with 1" step, ~1. cm diameter ionization spot. Ne+CO2+N2 (90-10-5)





Cathode current / Anode current, "20" means 0.2%



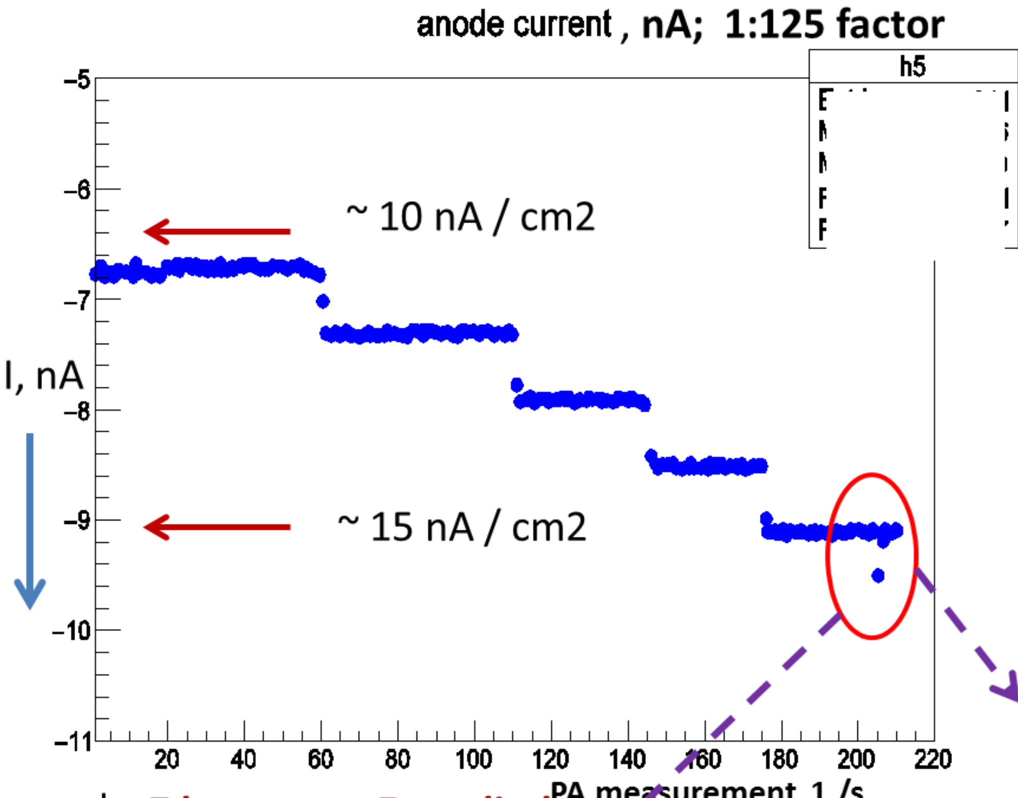
MMG+2 GEMs. IBF vs E-resolution

Red: standard setup (NIM A834, p149)

Blue: with R-layers, #1 need increase voltage on MMG and GEMs

Black: with R-layers, #2

Progress @ Yale: Performance comparison for two TPC readout options

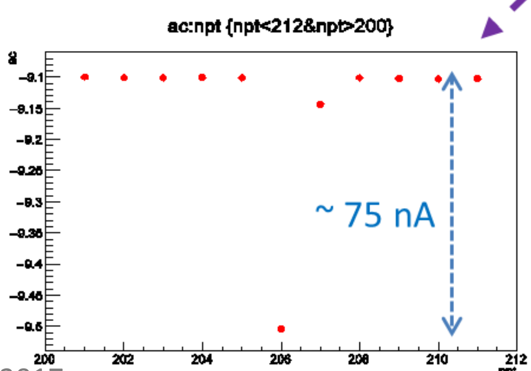


Standard MMG + 2 GEMs (HIROC)
Stability ("stress") test.
Full Chamber X-ray illumination.
Demands to pass:
Anode current: 10 nA/cm2,
6 hours, No discharges.

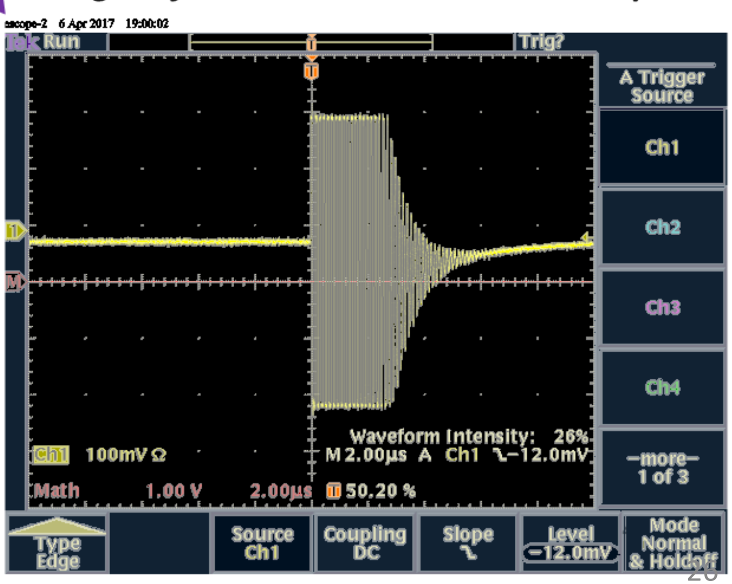
Setup is stable if there are no high momentum particles interacting with MMG mesh

< --- ~ 7 hours run, Zero discharges

~ 0.5 hour run, Zero discharges, →



Signal from MMG mesh to record sparks



eRD6 Consortium: Funding request for the coming cycle

- **Brookhaven National Laboratory (BNL):**
  - Continue zigzag pad development **(critical for EIC),** setup of GEM-based cosmic ray telescope
  - **GEM Studies using TPC gas mixtures, collaborate with Stony Brook group, (critical for EIC)**
- **INFN Trieste**
  - Complete the studies of novel materials for the THGEM PCB and the development of resistive MM with miniaturized pad size
  - **New proposal: Exploration of new photocathode based on NanoDiamond (ND) particles (critical for EIC)**
- **Stony Brook University (SBU)**
  - **New proposal: Ion flow back studies (critical for EIC)**
- **Joint UVa & Florida Tech proposal**
  - Assembly of large low mass GEM prototypes (u-v and zigzag strips readout), characterization at Fermilab Test Beam Facility.
  - Development of Large area Chromium GEM (Cr-GEM), simulation and prototyping
  - **New proposal: Development of cylindrical μ-RWELL for fast hit information in the central tracking (critical for EIC)**

Cost matrix

$k	THGEM	Zig-Zag Pads	TPC Gas Choice	μ-RWELL Studies	Chromium GEM Foils	Test Beam (lg chamb)	Ion Back Flow	TOTAL
BNL		63.0	12.0					**75**
Stony Brook							42.0	**42**
UVA				7.0		8.25		**15.25**
FIT				7.0	4.0	6.75		**17.75**
INFN	**50**							**50**
TOTAL	**50**	**63**	**12**	**14**	**4**	**15**	**42**	**200**

eRD6 Funding request: Breakdown per institute

BNL

Item	*Cost in $*	*-20%*	*-40%*
Production of new zigzag readout boards	*20K*	*10K*	*10K*
Gas & supplies	*8K*	*8K*	*8K*
Materials for X-ray scanner & cosmic ray telescope	*12K*	*12K*	*7K*
Additional readout electronics	*10K*	*10K*	*5K*
Subtotal	***50K***	***40K***	***30K***
Total w/overhead	***75K***	***60K***	***45K***

FIT

	Request	**-20%**	**-40%**
µ-RWELL prototypes	3.0k$	1.5k$	1.5k$
Chromium GEM foils	4.0k$	2.0k$	2.0k$
Gas at FNAL and other lab materials	1.75k$	1.5$k	1.0k$
Undergraduate student: Simul.	4.0k$	4.0k$	2.5k$
Travel to FNAL	5.0k $	5.0k$	4.0k$
Total	**17.75k$**	**14.0k$**	**11.0k$**

INFN Trieste

	cost (k$)	**INFN overhead** (k$)	**TOTAL (=cost+overhead)** (k$)
item			
manpower	20	4	24
travelling (3 trips to US + trips for material procurement and construction + BARI-TRIESTE travelling for the ND photocathodes)	10	2	12
consumables	14		14
total	**44**	**6**	**50**

SBU

	Cost	Overhead	Total	20% Reduction	40% reduction
Laminar Table	$7,034.00	$4,150.06	$11,184.06	$11,184.06	$0.00
Flow Controller Unit	$1,999.99	$1,179.99	$3,179.98	$3,179.98	$3,179.98
Circuit Cards	$4,000.00	$2,360.00	$6,360.00	$6,360.00	$6,360.00
Gems/mMEGAS	$5,000.00	$2,950.00	$7,950.00	$7,950.00	$7,950.00
pAmmeters	$5,370.00	$3,168.30	$8,538.30	$0.00	$0.00
Consumables	$3,000.00	$1,770.00	$4,770.00	$4,770.00	$4,770.00
TOTAL	$26,403.99	$15,578.35	$41,982.34	$33,444.04	$22,259.98

UVa

	Request	**-20%**	**-40%**
µ-RWELL prototypes	3.0k$	1.5k$	1.5k$
Gas at FNAL and other lab materials	1.75k$	1.5$k	1.0k$
Undergraduate student: Simul.	4.0k$	4.0k $	2.5k $
Travel to FNAL & FIT	6.5k $	5.0k $	4.0k $
Total	**15.25k$**	**12.0k$**	**9.0k $**

eRD6 Publication List: Breakdown per institute

❖ Brookhaven National Lab

1. "*A Study of a Minidrift GEM Tracking Detector*", B. Azmoun et.al., IEEE Transactions on Nuclear Science, Vol. 63, No. 3 (2016) 1768-1776.
2. "*A Prototype TPC/Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider*", C.Woody et.al., proceedings of the 2015 Micropattern Gas Detector Conference, European Journal of Physics (in press).
3. "*A Study of a Combination TPC-Cherenkov Detector using a CsI Photocathode and GEM Based Readout*", B.Azmoun et.al., in preparation for submission to the IEEE Transactions on Nuclear Science.
4. A paper entitled "Beam Test results from a Combination TPC-Cherenkov Detector" is currently being prepared for submission to the IEEE journal, Transactions on Nuclear Science in the coming weeks.

❖ Florida Tech

1. Manuscript in preparation: A. Zhang, M. Hohlmann, B. Azmoun, M. L. Purschke, C. Woody, "*A GEM readout with radial zigzag strips and linear charge-sharing response*," to be submitted to Nucl. Inst. Meth. A; presented also as a poster at the 2016 IEEE NSS, Strasbourg, France.
2. Manuscript in preparation: M. Bomberger, A. Zhang, M. Hohlmann, "*Mechanical design and stress analysis of a large-area gas electron multiplier*," in preparation for submission to Journal of Mechanical Design (JMD). This work was presented at the 2017 Florida Academy of Sciences annual meeting and received an "Honorable Mention Undergraduate Oral Presentation" award.
3. A. Zhang and M. Hohlmann, "*Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering*," JINST 11 P06012 (2016), June 21, 2016.
4. A. Zhang, V. Bhopatkar, M. Hohlmann, et al., "*R&D on GEM Detectors for Forward Tracking at a Future Electron-Ion Collider*", Proc. of IEEE Nuclear Science Symposium 2015, San Diego, CA; arXiv:1511.07913, Nov 24, 2015.
5. A. Zhang, et al., "*Performance of a large-area GEM Detector read out with wide radial zigzag strips*," Nucl. Inst. Meth. A 811 (2016) 30-41, online version at ScienceDirect (18 Dec 2015).

eRD6 Publication List: Breakdown per institute

- **INFN Trieste**

1. N/A; Just Started

- **Stony Brook University:**

1. M. Blatnik et al., "*Performance of a Quintuple-GEM Based RICH Detector Prototype*", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015.
2. M. Blatnik et al., "*Performance of a Quintuple-GEM Based RICH Detector Prototype*", Nuclear Science Symposium Conference Record, 2015, IEEE
3. Manuscript in preparation: "*First Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout*", to be submitted to the IEEE Transaction on Nuclear Science in early 2017.
4. Proceedings in preparation: "*First Results from a Prototype Combination TPC Cherenkov Detector with GEM Readout*", for the IEEE NSS/MIC 2016 in Strasbourg.

- **Univ. of Virginia**

1. K. Gnanvo et al., "*Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout*", Nucl. Inst. and Meth. A808 (2016), pp. 83-92. DOI: 10.1016/j.nima.2015.11.071
2. K. Gnanvo, et al. "*Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab*", Nucl. Inst. and Meth. A782, 77-86 (2015). DOI: 10.1016/j.nima.2015.02.017

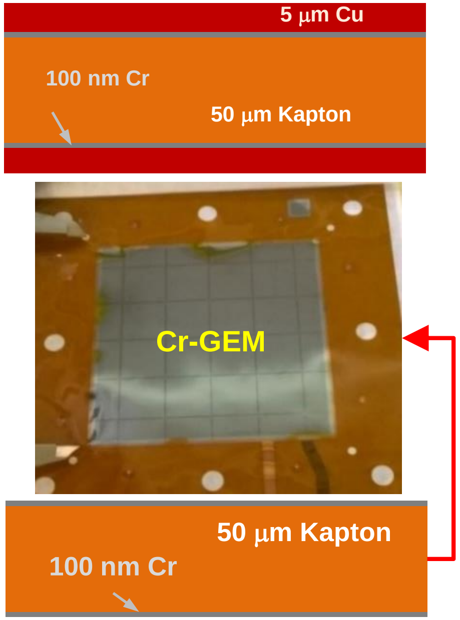
- **Yale University**

1. S. Aiola et al., "Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber", Nucl. Inst. and Meth. A834 (2016) 149-157.

Backup

Progress @ UVa: Results of the aging test of Cr-GEM with x-ray

Standard GEM



Triple-GEM with standard GEM foil

	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	5	8.96	14.3	1	0.0350	0.0045
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	5	8.96	14.3	0.8	0.1678	0.0215
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5	8.96	14.3	0.2	0.0070	0.0009
Copper-350	1	5	8.96	14.3	0.75	0.0262	0.0034
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	$\boxed{0.471}$	**0.090**

Triple-GEM with Cr-GEM foil

	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0	8.96	14.3	0.2	0.0000	0.0000
Copper-350	1	0	8.96	14.3	0.75	0.0000	0.0000
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	$\boxed{0.235}$	**0.060**

About 50% reduction in the amount of material in a EIC-FT-GEM with Cr-GEM

- 5μm Cu layers removed, 100 nm Cr used as electrodes
- 50% reduction of the material budget compared to light weight **triple-GEM**